Ortho-to-para nuclear spin conversion of H_2 on interstellar bare grain analogues

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The H_2 molecule has two nuclear spin isomers: ortho and para isomers. The energy difference between ortho and para state is as large as 14.7 meV (~170 K), and the nuclear spin conversion between these states is forbidden in the gaseous phase. Therefore, these isomers are often considered different species. The ortho-to-para ratio (OPR) is known to affect chemical evolution as well as gas dynamics in space. To understand the meaning of H_2 OPR determined from astronomical observations, the mechanisms that change the OPR should be clarified. In contrast to the gaseous phase mechanisms, in which spin exchange reactions with protons and hydrogen atoms alter OPR, little has been known about H_2 nuclear spin conversion (NSC) on astrophysically relevant surfaces. In this work, we investigated the H_2 NSC on interstellar bare grain analogues: silicate and carbonaceous materials [1,2].

In our experiments, time evolution of H_2 OPR on the surfaces was traced by using a combination of temperature-programmed desorption (TPD) and resonance-enhanced multiphoton ionization (REMPI) methods. H_2 with OPR = 3 was deposited onto amorphous-Mg_2SiO_4 or amorphous diamond-like carbon film kept at 10–18 K, TPD was initiated after certain waiting times after deposition, and desorbing ortho and para isomers were selectively ionized by the REMPI method and detected by a time-of-flight mass spectrometer.

The NSC time constants obtained for the surfaces of astronomical grain analogues [1–3] are plotted as a function of temperature in Figure 1. In each case, the NSC time constants became smaller as temperature increases. This temperature dependence indicates that surface phonons play an important role in the energy dissipation process associated with the H_2 NSC. Using a simple model considering collision rate of gaseous H_2 with grain surfaces, sticking probability, NSC time constant, and sublimation timescale of adsorbed H_2, we found that the H_2 NSC process especially on bare silicate grain surface is efficient to reduce the gaseous H_2 OPR within astronomically meaningful timescale.

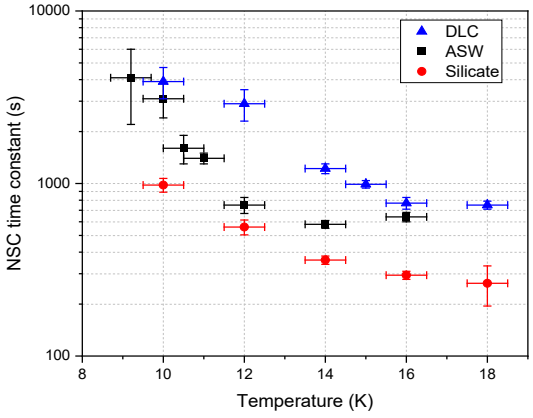

Figure 1: The plot of temperature dependence of the NSC time constants for amorphous diamond-like carbon (DLC, blue triangle) [1], amorphous solid water (ASW, black square) [3], and amorphous-Mg_2SiO_4 (silicate, red circle) [2].

References

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